

Measurement of the muon inclusive cross section in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector

Silvia Franchino
*Università di Pavia and INFN Pavia,
 Pavia,
 27100,
 Italy*

The measurement of the muon inclusive differential cross section $d\sigma/dp_T$ in pp collisions at $\sqrt{s}=7$ TeV with the ATLAS detector is presented. The analysis is performed in the pseudorapidity interval $|\eta| < 2.5$ for muon of transverse momentum $4 < p_T < 100$ GeV and with an integrated luminosity of 1.4 pb^{-1} . The result is compared with the next-to-leading order with next-to-leading log high p_T resummation prediction for the heavy flavour production and with MC@NLO prediction for W-Z bosons production. The measurement is sensitive for the first time to the next-to-leading log contribution to the heavy flavour production in hadronic interactions.

I. INTRODUCTION

High transverse momentum muons are a key signature of interesting processes in hadronic interactions. The spectrum of muons produced close to the interaction point in pp interactions is sensitive to heavy flavour production in the range $4 < p_T < 100$ GeV. A measurement in this region is useful to optimise theoretical models and effective MC generators in order to improve the evaluation of the heavy flavour production mechanism. Nowadays theoretical computations from pQCD are available allowing predictions of the muon spectrum from the QCD lagrangian and data-driven non perturbative corrections, dependent upon fragmentation functions extracted from LEP data and heavy flavours decays and form factors extracted from B-factories. These calculations have been performed at next-to-leading order (NLO) + next-to-leading log (NLL). No experiment up to now was sensitive to the NLL contribution. At high p_T the NLO+NLL prediction becomes in fact more accurate due to the reduction of the scales uncertainty and the deviation between the NLO computation and the NLO+NLL becomes larger. Here is presented for the first time the sensitivity to the next-to-leading log resummation at high p_T at a hadron collider. The inclusive muon yield provides also an important input to the muon trigger tuning and to the understanding of the background sources in the search for new particles with muons in the final state.

II. THE MEASUREMENT

The measured differential cross-section within the kinematic acceptance of the muon is defined by

$$\frac{\Delta\sigma_i}{\Delta p_{T_i}} = \frac{N_{\text{sig}_i}}{\Gamma_{\text{bin}_i} \cdot \int \mathcal{L} dt} \cdot \frac{C_{\text{migration}_i}}{\epsilon_{(\text{reco}+\text{PID})_i} \cdot \epsilon_{\text{trigger}_i}}, \quad (1)$$

where N_{sig_i} is the number of signal electrons or muons with reconstructed p_T in bin i of width Γ_{bin_i} , $\int \mathcal{L} dt$ is the integrated luminosity, $\epsilon_{\text{trigger}_i}$ is the trigger efficiency and $\epsilon_{(\text{reco}+\text{PID})_i}$ is the combined reconstruction and identification efficiency. $C_{\text{migration}_i}$ is the bin migration correction factor, defined as the ratio of the number of muons in bin i of true p_T and the number in the same bin of reconstructed p_T . Each of these contributions has been measured or estimated, as shown in [1].

From the measured inclusive prompt muon cross section, we subtract the contribution from $W/Z/\gamma^*$ production in order to obtain the cross-section corresponding to the decays of heavy-flavour hadrons produced in the pp collisions to muons. As better explained in Section 2.3, this contribution is estimated from the monte carlo simulation (normalized to measurements).

The spectrum of muons from heavy-flavour decays is calculated in a theoretical framework, FONLL [2], that allows direct comparison with the data. FONLL is based on three main components: the heavy quark production cross-section calculated in perturbative QCD by matching the Fixed Order NLO terms with NLL high- p_T resummation, the non-perturbative heavy-flavour fragmentation functions determined from e^+e^- collisions and extracted in the same framework, and the decays of the heavy hadrons to muons using decay tables and form factors from B-factories.

A. Data sample, selection efficiency and signal extraction

The analysis is based on a data sample collected at $\sqrt{s} = 7$ TeV during April-August 2010. The integrated luminosity used is $1.42 \pm 0.05 \text{ pb}^{-1}$. Simulated data samples have been generated in order to estimate backgrounds and correct for the trigger and

reconstruction efficiencies and the resolution of the detector.

Events were selected using the hardware-based first level muon trigger; a collision vertex with more than two associated tracks was also selected. Muon candidates were required to pass several identification criteria based on track matching and quality.

The trigger efficiency for the muon candidates is evaluated using events recorded by an independent trigger based on calorimeter information alone.

The efficiency for the lower threshold trigger is found to be 68% at $p_T = 4$ GeV and to reach a plateau of 84% at 9 GeV. The 10 GeV threshold trigger efficiency is constant for $p_T > 16$ GeV with a value of 74%. (The muon trigger efficiency is dominated by the limited acceptance of the muon trigger chambers).

Reconstruction efficiency has been determined from high-statistics simulated muon samples from heavy-flavour hadron and $W/Z/\gamma^*$ decays, with correction factors being determined by comparing the simulation-derived efficiencies with those observed in data. The overall reconstruction efficiency is found to be 85% at $p_T = 4$ GeV, reaching 95% at 7 GeV. The plateau value of 95% is the same for both isolated and non-isolated muons.

In addition to signal muons from charm, beauty and $W/Z/\gamma^*$ decays, the selected candidates comprise a significant fraction of background muons from pion and kaon decays in flight and misidentified muons from hadronic showers in the calorimeter that reach the muon spectrometer (MS) and are wrongly matched to a reconstructed inner detector (ID) track. The muon reconstruction provides independent information on the p_T of the track reconstructed in the ID and in the MS. The difference in p_T , $\Delta p_T = p_T^{\text{ID}} - p_T^{\text{MS}}$, where both momenta are extrapolated to the interaction point, is sensitive to the origin of the muons: signal, early- π/K , and late- π/K or fakes. A fit to the data distribution is performed to extract the signal component using templates from the simulation.

The signal purity of the sample was determined to be from 45% at $p_T = 4$ GeV to 90% at 40 GeV in the region of the W/Z Jacobian peak.

The muon momentum resolution has been studied using tracks from the decays $Z \rightarrow \mu^+\mu^-$ and $J/\psi \rightarrow \mu^+\mu^-$.

B. Inclusive muon differential cross section

The signal fraction of the muon transverse momentum spectrum has been corrected for the trigger and reconstruction efficiencies and unfolded from the detector response. Figure 1 Left shows the resulting inclusive muon differential cross-section for muons within $|\eta| < 2.5$ as a function of p_T , compared to the overall theoretical expectation. The expected W/Z component comes from MC@NLO using the CTEQ6.6

PDFs, normalised to the cross-section for muons measured by ATLAS [3]. The FONLL prediction is used for the heavy-flavour component and the remaining, small contributions are obtained from PYTHIA simulation. The theoretical uncertainty is dominated by the heavy-flavour prediction, being approximately 20%, and is not shown in the figure. The summary of systematic uncertainties on the muon cross-section measurement is shown in Table 1.

Integrating over the full 4-100 GeV p_T range, in $|\eta| < 2.5$, we find a fiducial cross-section for inclusive muons of

$$\sigma_{\text{Inc}}^\mu = 6.55 \pm 0.01(\text{stat.}) \pm 0.37(\text{syst.}) \pm 0.22(\text{lumi.}) \mu\text{b.}$$

TABLE I: Summary of systematic uncertainties on the muon cross-section measurement. The uncertainties apply in the p_T bins of the measurement; an interval or upper limit is given where the uncertainty varies as a function of p_T .

Source of systematic uncertainty	Cross-section uncertainty (%)
Possible bias in signal extraction	3
Early- π/K fraction	< 2
Stat. uncertainty on signal extraction templates	1–8
Efficiency scale factor	1.2
Trigger efficiency control sample statistics	0.4–0.9
Trigger efficiency control sample bias	< 2.3
Trigger efficiency background bias	0.2–0.7
Trigger efficiency mis-modelling of signal fraction	0.5–0.7
Unfolding procedure	0.1–1.2
Integrated luminosity	3.4
Total	5–8

C. Comparison with theoretical predictions

The measured muon cross-section compared with the predicted ones, is given over the full p_T (4-100 GeV) and pseudorapidity ($|\eta| < 2.5$) range in Fig. 1 (right). The measured heavy-flavour cross-section is compared to the FONLL calculations, with a rigorous evaluation of the associated uncertainty shown as a band in the figure. The theoretical uncertainties are around 20-40%, decreasing with p_T . The dominant contribution comes from the renormalisation and factorisation scales (up to 35% at low p_T). The uncertainty on the heavy quark masses contributes up to 9% at low p_T , and the PDF-related uncertainty is below 8% over the whole p_T range. Uncertainties arising from the value of α_s and from the non-perturbative fragmentation function are less than few

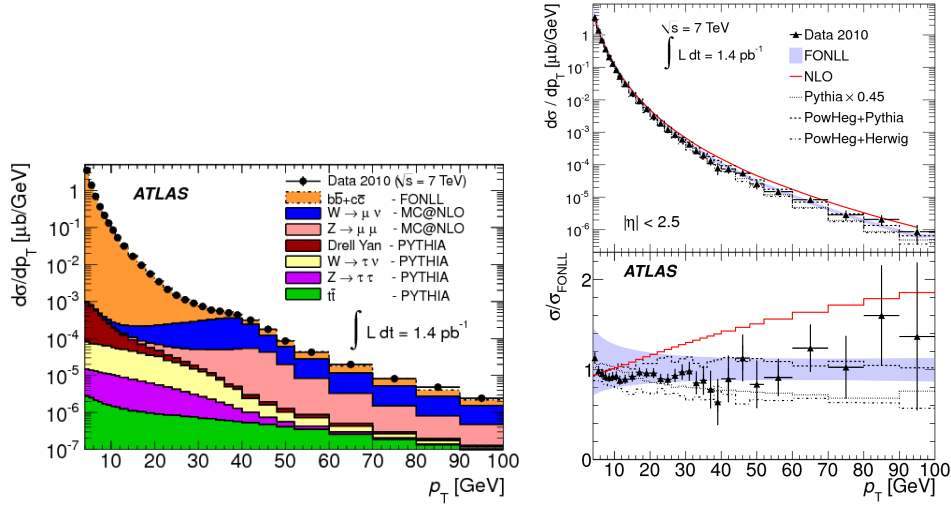


FIG. 1: (Left) Muon differential cross-section as a function of the muon transverse momentum for $|\eta| < 2.5$ compared to theoretical predictions from each contribution.

(Right) Muon differential cross section as a function of p_T after subtraction of the $W/Z/\gamma^{(*)}$ contribution and compared to the prediction of the FONLL and NLO calculations and predictions of PYTHIA, POWEG+PYTHIA and POWEG+HERWIG. The ratio of the measured cross-section and the other predicted cross-section to the FONLL calculation is given in the bottom of the plot.

percent.

The results are also compared to the NLO predictions of the POWHEG program, interfaced to either PYTHIA or HERWIG for the parton shower simulation, and to the LO plus parton shower predictions of PYTHIA. Whereas POWHEG+PYTHIA agrees well with the FONLL predictions, POWHEG+HERWIG predicts a significantly lower total cross-section. Less than half of this difference may be accounted for by the different heavy-flavour hadron decay models, checked by implementing a common decay simulation, EVTGEN, for both showering and hadronisation programs. PYTHIA (LO) describes the p_T -dependence well but predicts approximately a factor two higher total cross-section.

Comparisons are also made to the NLO central value expectation obtained from the FONLL program by excluding the NLL resummation part of the perturbative QCD calculation. Data deviate significantly from the NLO prediction, showing sensitivity to the NLL resummation term in the pQCD calculation for the first time in heavy-flavor production at hadron colliders.

III. CONCLUSIONS

The differential cross-section of muons arising from heavy-flavour production have been measured in the p_T range $4 < p_T < 100 \text{ GeV}$ within $|\eta| < 2.5$. The theoretical predictions for heavy-flavour production from the FONLL computation are in good agreement with the measurement.

Good agreement is also seen with the predictions of POWHEG+PYTHIA, although POWHEG+HERWIG predicts a significantly lower total cross-section. PYTHIA describes the p_T -dependence well but predicts approximately a factor two higher total cross-section. For muons with $p_T > 25 \text{ GeV}$ a deviation from the NLO central prediction is seen, indicating sensitivity of the heavy-flavour production data to the NLL high- p_T resummation terms.

[1] Measurements of the electron and muon inclusive cross-section in proton-proton collisions at $\sqrt{s}=7 \text{ TeV}$ with the ATLAS detector, ATLAS Collaboration, arXiv:1109.0525 [hep-ex] (2011) - Submitted to Phys. Lett. B.

[2] M. Cacciari, S. Frixione, M. L. Mangano, P. Nason and G. Ridolfi, JHEP 0407 (2004) 033.

[3] ATLAS Collaboration, ATLAS-CONF-2011-046 (2011).